**Literature Review on Dye Sensitized Solar Cells (DSSC)**

**Literature Review**

**1. Historical Background**

The historical backdrop of the sensitivity of materials such as semiconductors to bandwidth of light greater than that relating to the band – gap has been shown somewhere else. It is an intriguing union of photo electrochemistry and photosensitivity, in which both of them depend on photo sensitive affected by separation of electrons or charges at a interface of liquid – solid. (Grätzel, 2003) The silver halides utilized as a part of photosensitivity possess band gaps of the magnitude in the range of 2.7 to 3.2 eV, and are along these lines not sensitive to a significant part of the natural light (visible light), generally as it stands the TiO2 now utilized as a part of the photo – electrochemical gadgets. The principal panchromatic film, ready to render the picture of a scene reasonably into highly contrasting, took place after the work of Vogel in Berlin after 1873, in which he related dyes with the halide semiconductor grains. (Grätzel, 2003) The main sensitization associated with the photo – electrode took after presently, utilizing chemistry in its production. Although, the realization of the parallelism between the two techniques, a recognition that the same dyes on a basic level can work in both and confirmation that their working process is basically done by the infusion of electrons that are acquired from photo – energized dye molecules inside the conduction type of band that is made up of n-type semiconductor substrates. In ensuing years the thought created that the dye can work most effectively if it is chemisorbed on the semiconductor surface. (Grätzel, 2003)

Titanium dioxide was the semiconductor that was utilized for this purpose. The chosen material has numerous preferences for sensitized photochemistry also, photograph electrochemistry: it is broadly accessible, cheaper, biocompatible material, non-dangerous and hence is even utilized as a part of health care products and domestic applications. The standard dye at the time was tris (2,2´-bipyridyl-4,4´-carboxylate) ruthenium (II), the carboxylate capacity being the connection developed by the process of chemisorption to the oxide substrate. (Grätzel, 2003) Advance from that point, until the declaration in the year 1991 of the sensitized electro – chemical type of photovoltaic gadget with a change effectiveness around then of 7.1 percent under sun oriented brightening. That development has preceded dynamically from that point forward, with confirmed proficiency now more than 10%. (Grätzel, 2003)

**2. Introduction to DSSC**

Sunlight is one of the naturally and abundantly available sources of energy and researchers have been working from several decades to make maximum use of the sunlight to harness energy. Several innovations made in this regard involve energy storage, solar water heater and atomic waste degradation etc. One such innovation involve the use of sunlight is to generate electricity which is possible by storing the sunlight energy in batteries. (Kalyanasundaram and Grätzel, 2009) Until now, the photovoltaic technologies that are implemented commercially are basically dependent on inorganic materials that have disadvantages of high production costs and also preparation methods are high energy consuming methods. It was also noted that, materials such as CdTe are not available abundantly in nature and also are toxic in nature. Thus, the solution available to solve this issue is to make use of organic photovoltaic methods. But according to researchers, who conducted their study purely on organic photovoltaic said that the efficiency of operation of organic photovoltaic are much lesser than the efficiency obtained from the inorganic – based photovoltaic technologies. (Nazeeruddin, Baranoff and Grätzel, 2011)

Photo electrochemical solar based cell is by and large made out of a photoactive type of semiconductor material consisting of a working anode and a cathode and is either made up of semiconductors or metals such as Pt. Both cathodes are inundated in the solution of electrolyte which consists of appropriate redox mix. In the event that the semiconductor – electrolyte interface (SEI) is ignited with a light wave having energy more prominent than the semiconductor’s band – gap, photo – generated electrons / openings are isolated. (Robertson, 2006) The photo – generated minority transporters, settle down at the interface of semiconductor – electrolyte effectively. Photo – generated minority carrier transporters aggregate at the posterior position of semiconductor material. Taking the assistance of a charge – gathering substrate, photo – generated greater part bearers are transported by means of a heap to the cathode where these bearers respond electrochemically with the electrolyte solution of redox. (Robertson, 2006) A spearheading photo electrochemical investigation was acknowledged by getting photocurrent among two different cathodes made of platinum and inundated in the solution of electrolyte which also consists of metal halide salts. Later it was successfully discovered that by adding dyes to the metal halide salts, the wavelength range of photosensitivity can be enhanced to a greater extent. The enthusiasm for photo electrochemistry of semiconductors prompted the revelation of wet – sort photo electrochemical solar powered cells. Grätzel has then extended the idea to the Dye Sensitized Solar Cells (DSSC) by adsorption of colour particles on the nano – crystalline TiO2 cathodes. (Robertson, 2006)

Traditional natural photovoltaic gadgets utilize natural materials in the form of a donor and acceptor, which shape a hetero – junction supporting the division of the component called exciton in the two used carriers. Those framed carriers are shifted successfully to the cathodes by making use of the same materials that were used for the development of an exciton. In other words, material used for traditional natural photovoltaic gadgets ought to possess both great light storing and storing features and great carrier transfer properties and which is a troublesome errand to accomplish. (O’Regan and Grätzel, 1991) Also, it is notable to see that The Dye – Sensitized Solar Cell (DSSC) innovation isolates both the prerequisites as the production of charge is carried out at the interface of the semiconductor – dye and the transfer of charge is done by the solution of electrolyte and the semiconductor. In other words, it means that the enhancement of spectral based properties can be accomplished by changing only the dye, while the features or properties of carrier transport can be enhanced by advancing the synthesis of electrolyte and also the semiconductor. (Nazeeruddin, Baranoff and Grätzel, 2011)

The main refinement of a photo – electrode was accounted for in 1887. Nonetheless, the working system by infusion of wide range of electrons from the photo – energized dye atoms into the band of conduction type which is made up of n – type semiconductor substrates dates just from the 1960s. The idea created in the next years with to start with the chemisorptions of the dye on the semiconductor surface and after that the utilization of scattered particles to give an adequate interface range. Right now, champion cells utilizing ruthenium buildings show around 11% power change effectiveness under AM1.5 conditions. In general, DSSC is considered as a minimal effort and promising answer for take care of the vitality issue. (Nazeeruddin, Baranoff and Grätzel, 2011)

This research report will be focusing on the Dye Sensitized Solar Cells (DSSC). These are also called as Dye Sensitised Cells (DSC) and are solar cells of third generation and were designed to convert visible light into a form of energy (electrical). The Dye – Sensitized Solar Cells (DSSC) have acquired lot of popularity in quite some time because of the optimized optical properties such as transparency and dye, low cost of production and easy fabrication. (Mathew et al., 2014) DSSC are considered to be different range of advanced type of solar cells and are said to be artificial photosynthesis because of its way of absorbing light energy. It was the year 1991 when Dye Sensitized Solar Cells (DSSC) were invented by two Professors named Michael Graetzel and Dr Brian O’Regan in Switzerland EPFL (Ecole Polytechnique Federale de Lausanne. Sometimes DSSC are called as Graetzel Cell or also is abbreviated as GCell. (GCell, 2014)

Photovoltaic is a trending and promising renewable vitality innovation that transforms daylight to power, with wide potential to contribute altogether to taking care without bounds vitality issue that mankind faces. To date, semiconductor sun powered cells overwhelm business markets, with crystalline Si having a 80% offer; the staying 20% is for the most part thin film sun powered innovation, for example, CdTe and Cu. The previous is a roundabout band – gap semiconductor normally requiring a 300 -um – thick retention layer, and material and handling expenses are high. (Chiba et al., 2006) The last contains components that are harmful and of low plenitude in the Earth. However Cu frames the best performing dainty film sun based gadgets, showing an effectiveness of ~ (approx) 20 %, yet is more than 1.4 times as costly as CdTe and nebulous Si. A low – cost and earth neighbourly contrasting option to these strong state gadgets is the Dye – Sensitized Solar Cell (DSC). It is reasonable to get ready, and the light-weight dainty film structures are good with mechanized assembling. (Chung et al., 2012) Basically, DSSC is referred to as a disruptive technology which is designed and developed to generate electricity in light conditions spanning wide range including outdoor and indoor conditions and thus allowing users’ to convert natural light and as well as artificial light into electrical energy which can be used for a wide number of electronic gadgets. (GCell, 2014)

The DSC, which stands for dye – sensitized solar cell gives an actually and monetarily dependable option idea to current day p – n intersection photovoltaic gadgets. As opposed to traditional silicon frameworks, where in the material of semiconductor expect both the undertaking of light ingestion and charge transporter transfer the both capacities are isolated here. Light such as visible or artificial is consumed by a sensitizer, which is moored to the wide band’s surface hole oxide semiconductor. (Hara and Arakawa, 2003) Charge partition happens at the interface through photograph prompted electron infusion from the dye and then passes them to the conduction band. Carriers are transported in the conduction band of the semiconductor to the charge gatherer. Utilization of sensitizers consisting of a wide retention band that is in conjunction with oxide films made up of nano – crystalline morphology grants to reap a vast division of daylight. About quantitative transformation of occurrence of a photon in the electric current is accomplished over a vast otherworldly range stretching out from Ultra Violet to the close IR locale. General sunlight – based (standard AM 1.5) to the change efficiencies associated with current is of 10.6 % have been come to. Advanced solution of electrolytes in view of ionic fluids have successfully been produced that depicts brilliant dependability both under delayed light splashing and also high range of temperature stress. Thus, there are great possibilites to create the solar cells at comparatively lesser cost than traditional cells. (Grätzel, 2004)

Figure – 1 shows the pictorial representation of a thin layer of DSSC (Dye Sensitized Solar Cell).



Figure – 2 shows the layers present in a basic DSSC (exploded view).



Referring to Figure – 2:

1. TCO – stands for Transparent Conducting Oxide (WE – working electrode)
2. Mesoporous oxide – underlayer
3. Mesoporous oxide that is photoactive and consists of dye molecules that are coated
4. Electrolyte consisting of redox mediators
5. Sealing separator / gasket
6. Layer of Pt catalyst (finely divided)
7. TCO – Transparent Conducting Oxide (CE – counter electrode) (Kalyanasundaram and Grätzel, 2009)

Basically, a DSSC is made up of a number of layers and resembles structure of a sandwich that is made up of two oxide electrodes of conducting type and has a separation interlayer made up of an organic type of redox electrolyte. Mesoporous type of wide oxide layer is considered to be the major portion of a DSSC and is placed on a oxide substrate (conducting – type). Nano – sized particles that are sintered together are the fundamental blocks of the oxide layer and help in electronic conduction. It resembles a spongy – like structure and when it is dipped into a particular dye solution, it immediately picks all the dye molecules and forms a deep coloration. Whenever the solar cell is kept open to natural visible light, the dye D is electronically excited and transforms to D\*, which is excited state form of the solar cell. In this excited state, the solar cell has the capacity to fill electrons to the layer of conduction band that is a part of oxide semiconductor. (Kalyanasundaram and Grätzel, 2009)

**3. The principle of Operation of a dye-sensitized nano – crystalline solar cell (DSC)**

Figure – 3 illustrates the principle of Operation of the DSSC in a schematic manner.  A single layer of the chosen dye’s charge transfer is fixed to the nano – crystalline surface film. When the process called as photo excitation comes in contact with the single layer of charge transfer dye, and then an electron is injected inside the oxide’s conduction band. Then the dye’s state is later on bounced back to original state by donating an electron that is taken from the solution of electrolyte. Oxidized dye is used to recapture the conduction band by making use of the process of interception by regenerating the sensitizer of the iodide. Without actually any kind of permanent chemical transformation the device generates electric power. (Grätzel, 2003)



Figure – 3 Operating principle of the DSC (Dye – Sensitized Solar Cell)

The Figure – 4 illustrates the TiO2 (anatase) film which is acquired from scanning electron micrograph and stored by screen imprinting on a leading glass sheet whose function is to behave as a current collector. The TiO2mass is about 1 – 4 mg / cm2 and film thickness is normally about 5 – 20 µm. The layer morphology analysis depicts the pore size to be around 15 nm and the porosity is about 50 – 65 %. The common physical shapes of the nanoparticles of type anatase are pseudocubic, square – bipyramidaland stablike. Concurring to HRTEM estimations the (1 0 1) face is for the most part uncovered after by (1 0 0) and (0 0 1) surface introduction. (Grätzel, 2003)



Figure – 4 Scanning electron micrograph of TiO2 (anatase) film

A late option exemplification of the DSC idea is the sensitized hetero – junction more often than not with an inorganic wide band gap nano – crystalline semiconductor of n – type polarity as electron acceptor, the charge neutrality on the dye being re-established by an opening conveyed by the complementary semiconductor, inorganic or organic and of p-type polarity. The earlier photo – electrochemical variation, being further progressed being developed, has an AM 1.5 solar conversion efficiency of more than 10%, whereas that of the solid-state device is till greatly lower.  (Grätzel, 2003)

**4. Working of a Dye – Sensitized Solar Cell (DSSC)**



Figure – 3 Functioning of a Dye – Sensitized Solar Cell (DSSC)

Figure – 3 shows the schematic of working of a DSSC. Following is a six – step process of working of a DSSC:

1. The photoactive material that is present in a typical DSSC is the dye which has the capability to produce electricity the moment it is sensitized by natural visible light or artificial light
2. The photons present in the incoming natural visible light and artificial light are caught by the dye and uses the available energy to excite the electrons which resembles the functioning of chlorophyll in the process of photosynthesis
3. Next, the excited electrons are injected into Titanium Dioxide by the dye. (Titanium Dioxide is a white pigment that is usually present in white paint)
4. Conduction of electrons is done by nano – crystalline titanium dioxide, which is its crystallized form
5. A chemical electrolyte that is present in the DSSC cell completes the circuit by closing it so that all available electrons are returned to the dye
6. Movement of all the electrons back to dye is the main source to generate energy which can be easily stored in a rechargeable battery, any electrical device or super capacitor. (GCell, 2014)

**5. Characteristics of DSSC**

Following are the unique characteristics of a typical DSSC:

1. Conversion efficiency of high energy – Efficiency of a DSSC is same as that of a Silicon solar cell (amorphous type) which has been acquired during the process of development in the laboratory and efficiencies slightly greater than 10 % might be possible
2. Low – cost fabrication – The construction process of a DSSC is quite simple and the materials used in its fabrication are of low – cost. Thus, it is quite clear that the fabrication cost of DSSC is less than traditional solar cells.
3. Component materials abundant availability – Availability of various oxide semi conductors for instance, iodine, dye and TiO2is abundant in nature. Although there is limited availability of Ru metal deposits, the quantity of Ru complex that is been used in the DSSC is only approximately 1 x 10 -7 mol cm -2. If there is any issue of limited availability of resources of Ru complexes, use of organic dye photo sensitizers can be made. (Kalyanasundaram, 2010)
4. Potential for adaptable and colourful consumer goods – Transparent and colourful solar cells can be manufactured by making use of various types of dyes that is dependent on the application of the solar cell (DSSC). For instance, instead of window panes, use of transparent solar cells can be made. Also, in addition, the plastic substrate can be used instead of glass. This is only possible if processing of TiO2in lower temperatures is available. This factor expands the usage of a DSSC (Kalyanasundaram, 2010)
5. Environmental pollution is less – materials such as dyes, iodine and TiO2 that are used in Dye – Sensitized Solar Cells are not toxic in nature. Only possibility is the organic solvents component that is present in the electrolyte solution can harm to a certain extent. Researches that will be carried out in future must be focussing on generating a solid – state electrolyte that does not cause any harm to the environment
6. Recyclability is good – The organic dye photo sensitizers that are normally present on the electrode can be easily removed or wiped off by cleaning the electrode using any kind of alkali solution or also combustion, thus ensuring good recyclability of the Dye – Sensitized Solar Cell. (Kalyanasundaram, 2010)

**6. Present DSC Research and Development**

The perfect sensitizer which is for the purpose of solitary intersection photovoltaic cell changing over standard worldwide AM 1.5 visible light or sunlight to power ought to retain all light beneath a limit of about 920 nm magnitude wavelength. After the process of excitation, it ought to infuse electrons inside the surface of solid having quantum yield of solidarity. The excited state’s energy level ought to be very much coordinated to the lower band limit of the oxide’s conduction band to reduce energy losses amid the electron exchange response. The potential of redox ought to be adequately of very high magnitude such that it can be recovered through the donation of electron from the hole conductor or the redox electrolyte. At long last, it ought to be steady enough to support around 108 turnover cycles comparing to around 20 years of exposure to natural light. (Grätzel, 2003)

A great part of the research conducted in the field of dye chemistry is given to the distinguishing proof and blend of wide range of dyes coordinating these necessities, while holding the photo – electrochemical environment stability. The fixed dye group guarantees that it quickly amasses as an atomic layer after uncovering the layer film made of oxide to a dye arrangement. (Hara and Arakawa, 2003) This molecular scattering guarantees a high likelihood that, the moment when there is consumption of photon, the dye molecule’s excited state will be bought back to the normal state by electron infusion to the conduction band of the semiconductor material. The optical ingestion of a single layer of dye is feeble, a fact which initially was referred to as decision out the likelihood of high effectiveness sensitized devices, as it was expected that smooth substrate surfaces would be basic all together to keep away from the recombination loss component related with rough or polycrystalline structures in solid – state photovoltaic. (Grätzel, 2003)

**7. Performance of State of the Art**

The solar cell development and research takes place in three stages:

Step – 1 – Firstly optimization research is done mostly in small (< 1 cm­­2area) cells

Step – 2 – Secondly there are modules which are second phase of solar cell development. These are larger in size (around 25 – 100 cm2).

Step – 3 – Thirdly large area tea terrestrial units are considered for solar power generation. These are much larger and are made up of many components connected either in parallel or series. The normal panel sizes at this level are around 0.5 to 2 m2.Broad exploration in numerous research centers over the globe has prompted huge advancement in acquiring progressively higher solar based light change efficiencies, both at the lab cell levels furthermore in bigger components.

Table – 1 give an outline of the best execution information got (best in class) to date in solar based light transformation, and in addition open circuit voltages (VOC) at different fill components (FF) utilizing different dyes for various surface ranges.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Dye | Surface (in cm2) | Efficiency (in %) | Voc (in V) | Isc (mA \* cm-2) | FF (in %) |
| N – 719 | < 1 | 11.2 | 0.84 | 17.73 | 74 |
| N – 749 | 0.219 | 11.1 | 0.736 | 20.9 | 72 |
| N – 749 | 1.004 | 10.4 | 0.72 | 21.8 | 65 |
| N – 719 | 1.31 | 10.1 | 0.82 | 17 | 72 |
| N – 3 | 2.36 | 8.2 | 0.726 | 15.8 | 71 |
| N – 749 | 26.5 | 6.3 | 6.145 | 1.7 | 60 |

Table – 1 Record performance of Dye Sensitized – Solar Cell (DSC) of different device sizes

Improvement in the light absorption properties of dyes especially in the close IR area (700-900 nm) will prompt higher photocurrents and light change proficiency.

For actual practical applications, dye sunlight based cells need to meet stringent strength prerequisites. For a lifespan of >10 years, the dyes must be stable to reversibly experience a large number of oxidation and lessening cycles. In tropical nations, surface board temperatures can without much of a stretch surpass 60 °C. Consequently, sun oriented cell modules ought to be tried for security at raised temperatures up to 80 °C under high mugginess conditions. With low boiling solvents, erosion of the seal can likewise make security issues. Consequently, current endeavors are coordinated towards utilizing low-temperature liquid salts (ionic fluids, for example, alkylimiadazolium halides). Utilizing long-chain alkyl substituent on the bpy ligand as in the dye Z907 and ionic fluid based electrolytes, it is conceivable to keep up redox dependability for more than 1,000 hours of constant enlightenment. Outside investigations of modules have exhibited a few special components of DSCs, for example, higher sun based vitality change under diffuse light conditions and positive temperature coefficients.